Response Bias in Tone Glide Direction Identification

A Senior Honors Thesis

Presented in Partial Fulfillment of the Requirements for graduation *with research distinction* in Speech and Hearing Science in the undergraduate colleges of The Ohio State University

By

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Dedication

I would like to dedicate my undergraduate honors thesis to my parents who have supported me throughout this whole process. It is through their guidance and support that I realized my dream of Speech and Hearing. Thank you for always advising me to pursue my dream and do my best every time.

Abstract

The average human listener has no difficulty encoding speech. Speech sounds are the different patterns of resonance in the vocal tract identified as formants. Formant transitions, rising or falling in frequency, are fundamental to the understanding of speech. Two previous studies reported that listeners are able to identify the direction of rising frequency sounds more accurately than those falling in frequency. However, the earlier studies did not measure or control for response bias. That is, the possibility that listeners simply respond “Up” more often than “Down” when they are uncertain about their perception. In this experiment, frequency modulated (FM) tone glides were used rather than the formant characteristic in speech. Four young adults between the ages of 18-22 with normal hearing performed the task of listening to a frequency-modulated tone. They then had to decide if it was a rising or a falling tone. The actual frequency of the tone was randomized so that a response could not be made based on the starting or ending frequency of the tone. An adaptive tracking procedure was used to determine the glide duration for which a listener could achieve: 62.5 percent, 75 percent, or 85.5 percent correct when they were asked to report the direction of the frequency change. The adaptive tracking task, Single Interval Adjustment Matrix, SIAM, is designed to counteract response bias in these listening tasks. Each percentage was tested with three center frequencies: 734, 1224, 2449 Hz. This experiment examined if all four subjects were able to recognize rising frequency glides with better accuracy than falling frequency glides at all three center frequencies. In addition to this experiment, another experiment was run to compare the data from the same subjects. The second experiment replicated the Dawson experiment which did not control for response bias. The data from the two were compared to eliminate any individual differences. This experiment used a statistical analysis to see if the previous findings were in fact true or if there is a response bias from listeners.

Acknowledgements

I would first like to thank my project advisor, Dr. Lawrence Feth, for all of his insight, patience, guidance, and support throughout this past year. His help has shown me how interesting research can be and how there are always surprises in research. Thank you for getting me interested in doing a senior honors thesis and working in the psychoacoustic lab.

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Chapter One – Introduction/Literature

Listening to speech is quite effortless for the average human listener. Children learn the elements of language at a very young age, and as they develop they put little thought into how they process the words. As people speak, the words must be encoded into a stream of sound energy that can be understood by a listener. For the words to be encoded the speaker must force air from the lungs through the opening in the larynx, glottis, and have the air exit through the oral cavity. In speech articulation, a consonant has a very short duration that is characterized by an obstruction in the vocal tract. Consonants can be characterized as voiced or unvoiced. In contrast, vowels contain no obstruction of the airway and have a longer duration and are voiced.

The shape of the vocal tract and the length of the vocal cords impact the type of sounds produced during speech. A person with longer vocal chords produces speech at a lower fundamental frequency than a person with shorter vocal chords. Additionally, high frequency vibration is made when the vocal folds stretch and tense. This is similar to strings on a guitar, shorter vocal folds or more tension on a string produces a higher rate of vibration and a higher pitch. The shape of the vocal tract and articulation of different consonants results in a filtering of the fundamental frequency produced by the vocal folds. The resonating frequencies caused by the filters are the formant frequencies. The formant frequencies are determined by the shape and the length of the vocal tract. Consequently, moving the articulators such as the velum and tongue the shape and the length of the vocal tract changes which results in a shift of the formant frequencies. In addition, each stop consonant changes the shape of the vocal tract, which affects the resonant frequencies. These changes in frequency are called formant transitions. The first formant (F1) usually increases; however, the second formant (F2) and third formant (F3) can increase or decrease depending on the place of articulation.

These small changes in formant transitions are accountable for the distinction between two different sounds. In addition, speech discrimination depends on the ability of the listener to detect acoustic cues, like the direction of the second formant frequency. Experimental research has focused on the ability of human listeners to distinguish between acoustic cues without using speech, but by using simple sounds that have characteristics of speech. In experimental settings, tone glides were set to be near the acoustic characteristics of formant transitions. The ability of a listener to identify a rising or a falling tone glide can show a difference in detecting one speech sound from another. This idea has led to research on the differences in performance of direction identification in up and down tone glides.

Literature:

The motivation to conduct this study relates to two previous studies on tone glide direction identification. Gordon and Poeppel (2002) observed the ability of normal hearing human subjects to distinguish between frequency-modulated (FM) tone glides moving “up” or “down” in frequency by altering the frequency range and the glide duration. Their study focused on the difference between rising and falling glides using a one-interval experiment with rapid frequency-modulated (FM) tones at different frequency ranges and durations. The participants in this experiment had normal hearing with no history of hearing or neurological problems. They used three frequency ranges: 0.6-.0.9 kHz, 1-1.5 kHz, 2-3 kHz, and ten durations: 5, 10, 20, 30, 40, 50, 80, 160, 320, and 640 ms. The three frequency ranges were chosen because they have typical values for the first formant (F1), second formant (F2), and third formant (F3) in normal speech. Each participant was asked to respond after being presented with a tone either rising or falling in frequency by pressing one of the two keys labeled “up” or “down”. The experiment was designed to test both the accuracy in direction identification and the reaction time.

Gordon and Poeppel found a difference in the subject's ability to identify rising and falling FM sweeps, when a short duration was used. They used a psychometric function to report these findings. A psychometric function plots the duration on the x-axis and the percent correct on the y-axis. The shape of the function is an s-shape that tracks the answers of the subjects. Then the function modifies the duration in one level increments (Yost, 2006). The results of Gordon and Poeppel's experiment indicated that upward tone glides were detected with better accuracy than downward tone glides when the durations were shorter than 160 ms. The most noticeable difference took place in the mid to high frequency ranges. When the rate of the sweep was 640 ms, subjects could identify both rising and falling glides at about 95%. When the sweeps were as short as 5 ms, the subjects were guessing between whether the tone was rising or falling.

In 2004, Dawson and Feth performed a study to examine if virtual-frequency (VF) tone glides would show the same difference in rising and falling tones as the Gordon and Poeppel experiment. Dawson and Feth not only examined listener performance in detecting the direction virtual-frequency (VF) glides but also used frequency-modulated (FM). Virtual-frequency tone glides are produced by presenting two tones that are close in frequency, but they only perceive one tone, a *virtual tone*, with a frequency between the two tones presented (see Figure 1). By increasing and decreasing the intensity of the two tones, the virtual-frequency tone can be perceived as rising or falling in pitch.

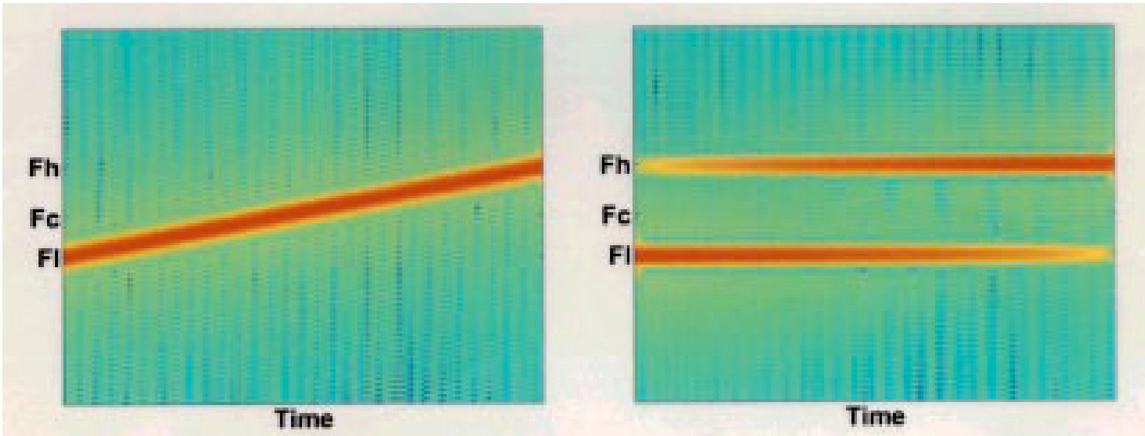

Figure 1- The left image represents an FM tone glide. The right image represents the VF tone glide which reversed the amplitudes of two constant frequencies over time. (Anantharaman, and Feth 2004)

Gordon and Poeppel found the clearest difference in direction identification form FM tones in the high frequency range from 5 to 160 ms; therefore, Dawson and Feth first tested FM tone glides fitting these criteria. Once the results matched Gordon and Poeppel's, Dawson and Feth could test VF tone glides. The initial test discovered the task was too easy and the subjects were able to identify both rising and falling tone glides with 100% accuracy. This suggests that Gordon and Poeppel had naïve listeners who were able to detect the direction of the tone glide by hearing only the beginning or ending frequency. To make the task more difficult, Dawson and Feth introduced roving FM glide frequencies. Roving refers to the center frequency being drawn from a uniform distribution of frequencies covering one octave around the nominal center of the frequency range. This causes variation in the beginning and ending frequencies for each glide. This forces the subject to listen to the full duration of the tone glide before determining the direction.

There were eight signal durations used during this experiment: 5, 10, 20, 30, 40, 50, 80, and 160 ms; all the signals were in the high-frequency range from 2000 to 3000 Hz. The virtual-frequency tone glides were produced by modulating the amplitudes of the two ending frequencies of the frequency-modulated tone glide. Each trial contained either an FM or VF signal with a constant duration, while the direction of the tone glide was randomly chosen. Similar to Gordon and Poeppel's experiment, listeners were asked to choose between two keys, one representing the rising tone glide or "Up" and another for the falling tone glide or "Down". This was a simple yes-no procedure that was used in both experiments.

The results of this experiment were similar to Gordon and Poeppel. Once Dawson and Feth introduced roving to the stimulus to make the task more difficult, they were able to find a difference in rising and falling tone glides. They found that listeners could identify a rising tone glide more accurately than a falling tone glide. Additionally, they found that the direction of FM tone glides were easier to detect than the direction of the equivalent VF tone glides in the same conditions. Figure 2 presents the graphical results of each subject in the Dawson and Feth (2004) experiment. It shows the difference in sensitivity between "Up" tone glides and "Down" tone glides.

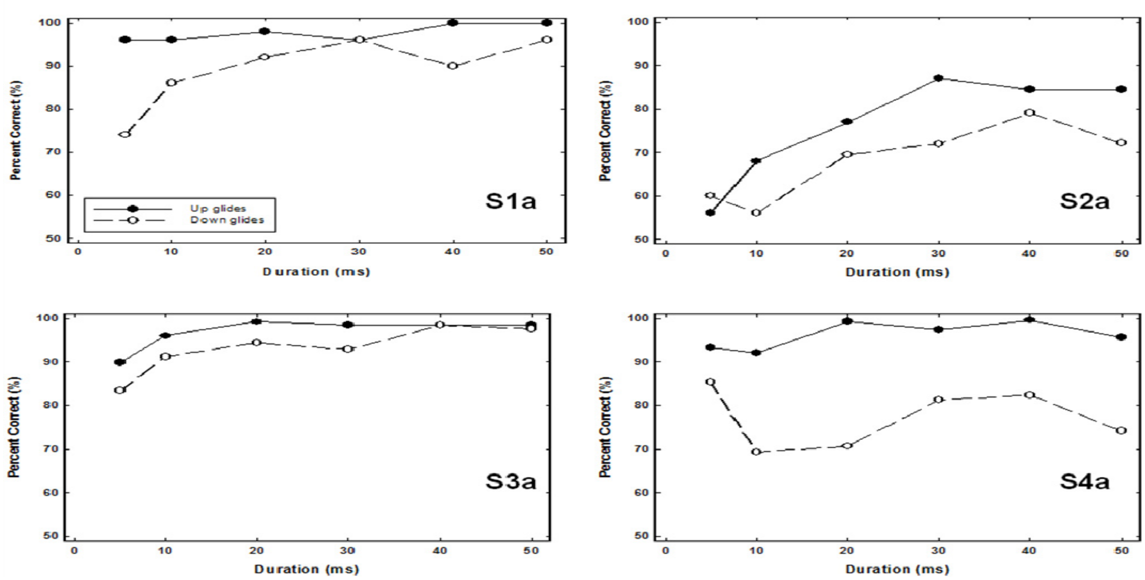

Figure 2 - Individual subject results from Dawson and Feth (2004) one-interval up/down experiment. UP glides are represented by filled circles, and DOWN glides are represented by open circles.

Response Bias:

The results of the previous studies suggest that the listeners were more sensitive to rising tone glides than falling tone glides. Both of these experiments used a performance task that was based on a single-interval experiment. The experiment results may have been influenced by response bias. Many reviews suggested that the subjects may have been biased toward answering "Up" rather than "Down" when the task became difficult. The subject may have been answering "Up" or "Down" based on where the label key was in the experiment setting. The experiment assumed the listener would identify "Up" half of the time and "Down" half of the time. To eliminate this bias, the new study used a single-interval adjustment-matrix procedure, SIAM procedure. This procedure is based on a "yes-no" task where it contains randomly presented signals. SIAM is an adaptive procedure that adjusts the signal level according to the listener's answers. For example, when the listener is doing well the task becomes more difficult and the task becomes easier as the listener answers incorrectly (Kaernbach, 1990). A unique aspect of the SIAM procedure is it calculates the hit, miss, false alarm, and correct rejection of each trial. For this particular experiment the subjects participated in two rounds of the SIAM procedure where one round targets for the "Up" tone glide and the other round targets for the "Down" tone glide. For each round the hit, miss, false alarm, and correct rejection rates were calculated. For example when the "Up" tone glide is being targeted the hit represented the subject identifying the rising tone glide accurately. The miss represented the subject not identifying the rising tone glide accurately. The false alarm represented the subject identifying the tone as rising when it is falling and the correct rejection represented the subject identifying the tone as falling when it is falling. The hits and the correct rejections was added together to identify how well the subject performed on each trial.

In order to eliminate any response bias, the new study on direction identification used the single-interval adjustment-matrix procedure or SIAM. Roving the tone glide will make the subjects listen to the whole stimulus to identify if the signal was rising or falling. Once the subjects listen to all of the tasks using the SIAM procedure, the subjects participated in a follow-up experiment. The follow-up experiment replicated the original study in the same testing conditions to see if the listeners would exhibit the same response bias shown in the previous study. In the simple "yes-no" procedure the subjects listened to the same signal but the duration stayed constant.

Questions that will be addressed:

- First, Does the SIAM procedure exhibit the same performance pattern in the difference between rising and falling tone glides as previous studies found?
- Second, by using the SIAM procedure that controls for any response bias, is there a difference in sensitivity between rising and falling tone glides?
- Finally, does the replicated "yes-no" procedure show any bias between rising and falling tone glides that was seen in previous studies?

Chapter 2 – Methods

Subjects:

The subjects for this experiment were four, normal-hearing undergraduate students with no history of hearing loss or neurological problems. They were all female and were between the ages of eighteen to twenty-two years old at the time of the experiment. A hearing screening was given to each listener to ensure they had normal hearing thresholds before participating in the experiment. For consistency, the subjects were asked to use their right ear throughout the entire experiment process. A Matlab program was used to generate the stimuli. The subjects listened to the tones through Sennheiser HD 580 supra-aural headphones, at a comfortable supra-threshold level for the listener.

The participants were asked to come in to the psychoacoustic lab in two hour blocks. They were tested in a single walled sound attenuating booth. The subjects would open Matlab and follow the instructions to open the SIAM procedure and the simple “yes-no” procedure. They were asked to take breaks between trials to ensure they were not feeling fatigued in the sound booth. To compensate for their time, the volunteered subjects were reimbursed for each hour; three out of the four subjects were paid. The investigator served as one of the subjects in the experiment. Each subject practiced the task until they were comfortable with the task. Once this was reached, the subjects were ready to begin the procedure for data collection.

Experimental Stimuli:

This study of direction identification used a single-interval adjustment-matrix (SIAM) procedure in order to eliminate any response bias and a simple “yes-no” procedure to use for comparison between the previous listener results and this study’s listeners. Both experiments used linear frequency-modulated (FM) tone glides. The “signal” interval was either an upward or downward frequency sweep. Each frequency was roving to make the subject listen to the entire "signal" in order to identify if it was a rising or a falling tone glide. The signals were produced across three center frequencies: 734, 1224, and 2449 Hz. Each center frequency was targeted for three percent corrects: 62.5%, 75%, and 87.5% (Kaernbach, 1990). To begin the SIAM procedure the stimulus duration was 50ms and the signal was presented at 70 dB SPL.

The follow-up study for direction identification used a one-interval yes-no procedure. This procedure was used to see if the subjects would show the response bias evident in the Dawson and Feth study under the same testing conditions. Again, the same center frequencies and targeted percent corrects were used to compare the data. In addition, roving was continued for the signal to stay constant with the previous experiment.

<u>Procedures:</u>

The subjects listened to three blocks of 50 trials at each center frequency: 734, 1224, and 2449 Hz and for each percent correct: 62.5%, 75%, and 87.5%. The subjects had to listen to the same frequencies and percent corrects for rising glides and for falling glides. Therefore, a total of 18 blocks and 2700 trials that were used in determining the average for each subject at each center frequency and at each targeted percent correct for down and up glides. During each trial in the block of 50 trials, the subjects listened to a roving tone glide. They then had to choose whether the tone glide was rising or falling. The direction of the glide varied between the blocks in the trial.

In the SIAM procedure experiment, the task would become more difficult when the subject performed well and easier when the subject performed poorly because the signal duration would reduce when the subject performed well and increased in when the subject performed poorly. This helps in eliminating any response bias because it makes the subject listen to the tone to identify if it was rising or falling. In the one interval yes-no procedure, the signal duration was set by the experimenter and the signal duration did not change when the subject did poorly or well.

The one interval "yes-no" procedure had a different way of determining the duration for each center frequency for each target percent correct. To make sure the experiment targeted the same percent correct as the SIAM procedure, the duration had to be calculated by averaging the means of the center frequencies. The average of three trials for each center frequency was averaged and then rounded to the whole number. This was done for each subject and was different between the up tone glides and down tone glides. The subject then manually type in the duration level for each trial by looking at their experiment sheet.

The subjects were allowed to hear each interval only once, and must then choose their response. The subjects pushed the left button if they thought the signal was an upward tone glide and the right button if the signal was a downward tone glide. Additionally, subjects were given visual feedback following each choice to reveal if the tone glide was upward or downward. The feedback aided each subject during the practice sessions.

Figure 3 demonstrates the screen the subjects used to chose their responses for each trial. Before each block, a red "warning" light would illuminate to notify the subject that the experiment was ready to begin. The subject then clicks on either mouse button to begin. The roving tone glide is presented. Once the subject hears the tone glide the "awaiting answer" light appears in the middle of the screen. This is when the subject knows they should determine if the tone glide was moving upward or downward. The subject must then click the left box if they thought the signal was moving upward or click the right box if they thought the signal was moving downward. Once the answer is submitted the light on the top right-hand side quickly flashes indicating that the answer was received. Quickly afterward the correct box lights up to reveal the correct answer to the subject. This gives the subject feedback to every response.

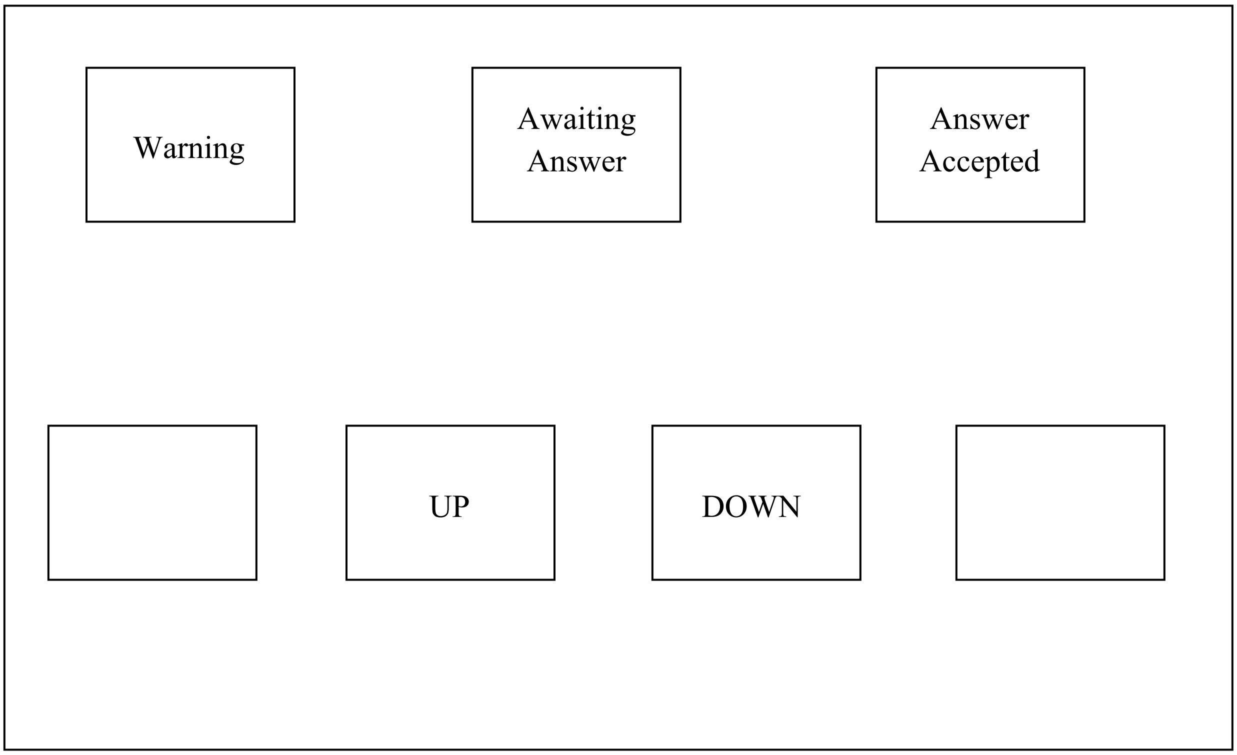

Figure 3 – A representation of the screen display seen by subjects who performed in the SIAM procedure and the one interval yes-no procedure.

Both experiments were randomized by the examiner for each subject. The subjects had to follow the order of the signals listed on their experimental sheet. First, the tone glide was randomized between upward and downward intervals. This was randomly chosen for them by the experimenter and each subject had a different variation of signals listed on their experimental sheet. This allowed the subjects to vary the amount of times they performed an upward trial and a downward trial. Additionally, the direction of the tone glide was randomized. On average, the tone glide was upward in frequency in half of the trials and downward for the remaining half of the trials.

For the adaptive procedure the computer calculated the mean and the standard deviation of the 50 trial. The computer also showed a graphical representation of how the subject answered for each trial. These means were then used to formulate various psychometric functions in order to analyze the results. For the non-adaptive procedure the computer calculated the hit, miss, correct rejection, and false alarm rates for the 50 trials. The study added the hit and correct rejection rates to determine if the subject was near the targeted percent correct.

Chapter 3 – Results

After several hours of subjects participating in the research, there was a significant difference between the previous studies and the new study. Since the adaptive procedure data was different than the Dawson and Feth (2004) results, the follow-up experiment was administered to the same four subjects to check for any subject bias. Once both experiments were finished, the data was compared between the two studies to identify the sensitivity between the rising and falling tone glides.

When analyzing the results the questions asked were:

1. Is there a difference between the subjects between rising and falling tone glides?
2. Was the non-adaptive procedure able to target the specific percent correct?

All four subjects were all normal-hearing undergraduates, small individual differences were found. For example, some of the subjects required more practice in order to master the task. Others did not show any need for practice. In addition, there was a difference in subject results in the non-adaptive procedure.

Subject #1 did not require much practice in order to start the experiment for data collection. The subject performed very well in the adaptive procedure and showed no difference in sensitivity between "Up" tone glides and "Down" tone glides. The 62.5% and the 75% correct were both the same for the rising and falling tone glides. The subject performed the same in the non-adaptive procedure. It showed there was again no difference in sensitivity between rising and falling tone glides. The rising and falling tone glides were both favored equally in the targeted 75 percent correct.

Subject #2 required some practice before data could be collected. The adaptive procedure showed that the subject did not have any difference in sensitivity between the "Up" tone glide and the “Down” tone glide. Both rising and falling seemed to match up quite nicely with the targeted percent correct (Figure 4). It can be seen in the 75 percent correct that the subject showed no difference in sensitivity between the “Up” and “Down” tone glide. In the non-adaptive procedure the subject again showed no difference in sensitivity in the 75 percent correct data. In addition, the subject did not show any difference in sensitivity between rising and falling tone glides. The subject performed better in the 62.5 percent correct because of the inability to make the task difficult for the subject (Figure 7).

Subject #3 the investigator, had the most practice prior to performing the set of trials used in the final data. Although results were being produced early on, the subject had to engage in hours of extra practice to search for the experimental parameters. The subject also had to understand the tone glide to explain what the other subjects would hear when they were participating in the experiment. For the adaptive procedure, the subject showed only a small difference in sensitivity between rising and falling tone glides. Contrary to previous studies, the subject actually favored the “Down” tone glides rather than the “Up” tone glides. This is shown in figure 4.1. It can be seen that the “Down” tone glide was more preferred in the targeted percent correct of 75%. In the non-adaptive procedure, the subject did much better in the task for each targeted percent correct (Figure 7). It seemed the subject did better for the 62.5% because the duration could not become short enough. This can be seen in Figure 5. The non-adaptive procedure also found the same sensitivity between the rising and falling tone glides.

Subject #4 required the least practice before participating in the experiment. For the adaptive procedure, the subject demonstrated a small difference in sensitivity between “Up” tone glides and “Down” tone glides. Similar to subject #3, the subject seemed to favor the “Down” tone glides more than the “Up” tone glides (Figure 4). In the non-adaptive procedure the subject performed better than the targeted percent correct. This is one common result that was foreseen. Overall, the subject had similar sensitivity for rising and falling tone glides but was more sensitive to the non-adaptive procedure than the adaptive procedure (Figure 5).

Upon further look at the subjects graphical representation of their data, it was evident there was a difference. In the adaptive procedure it was shown that two subjects showed a small difference in sensitivity between the rising and falling tone glides; however, unlike the previous experiments the subjects favored the “Down” tone glide rather than the “Up” tone glide. The other two subjects presented with no difference in sensitivity between the rising and falling tone glide which also goes against the previous findings.

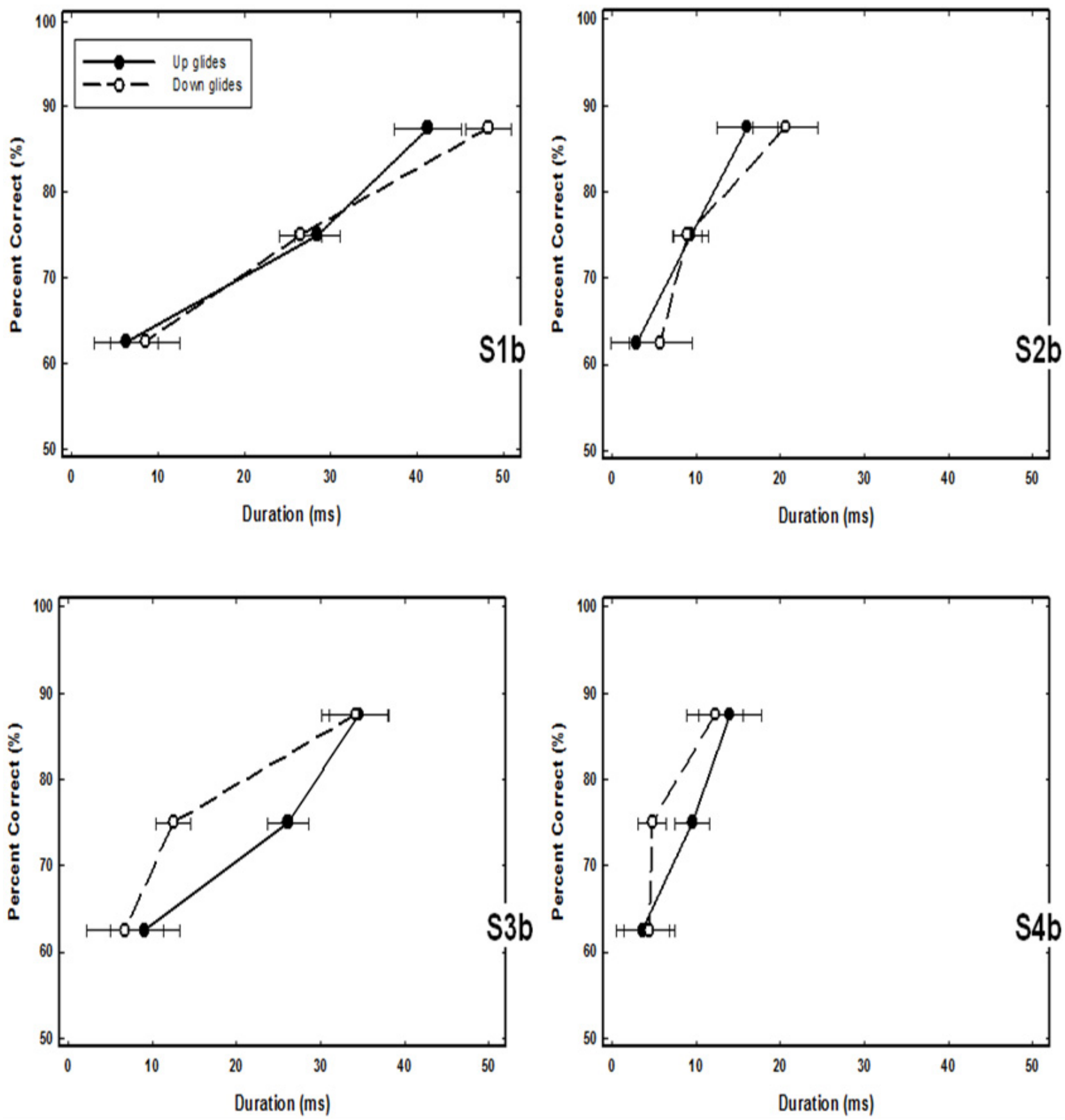

Figure 4- Individual subject results of the adaptive SIAM procedure. UP glides represented by black filled circles, DOWN glides represented by open black circles.

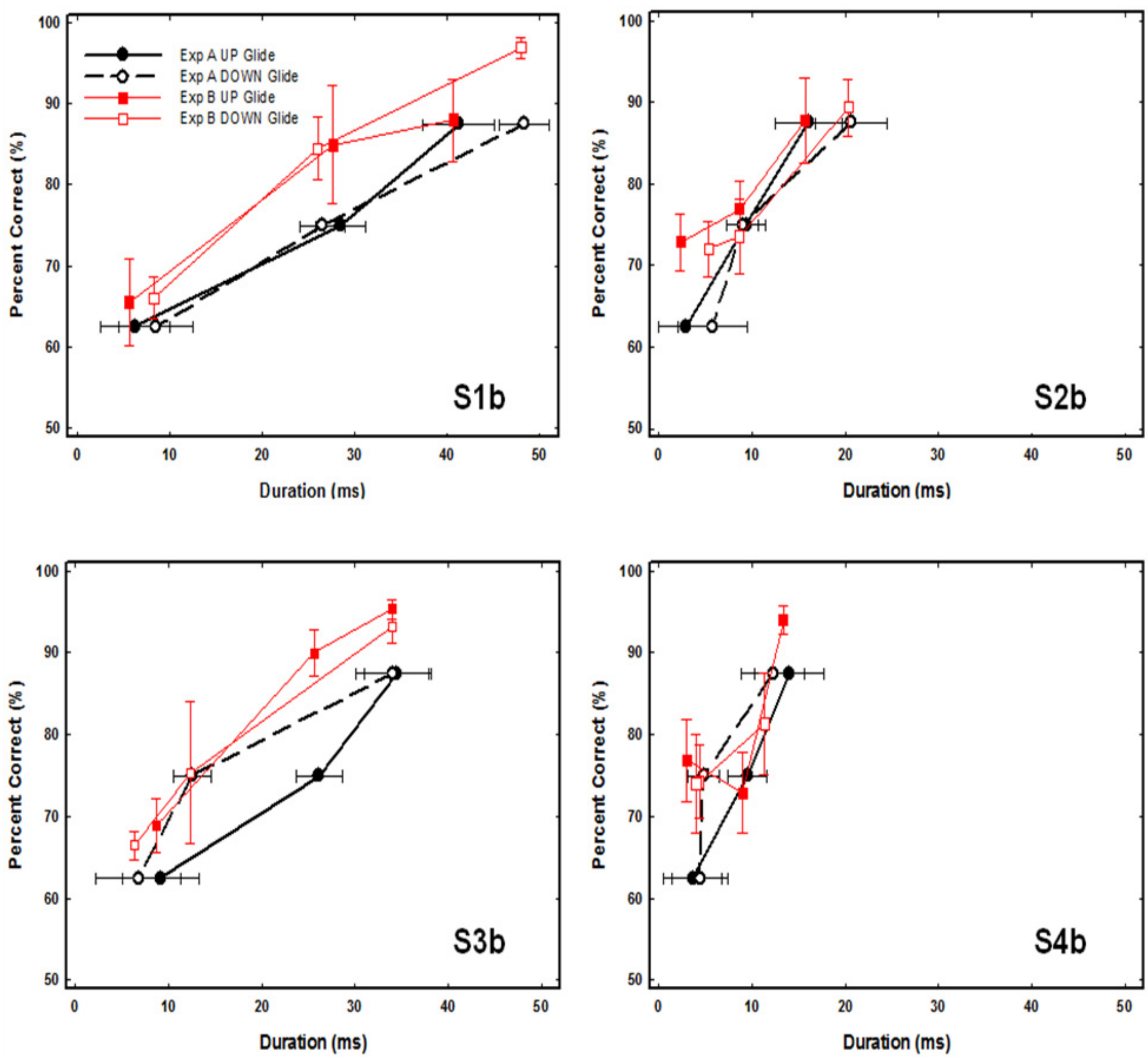

Figure 5 - Individual subject results of the adaptive SIAM procedure where UP glides represented by black filled circles, DOWN glides represented by open black circles. The red graph represents the same individual subject results of the non-adaptive procedure. UP glides represented by red filled circles, DOWN glides represented by open red circles

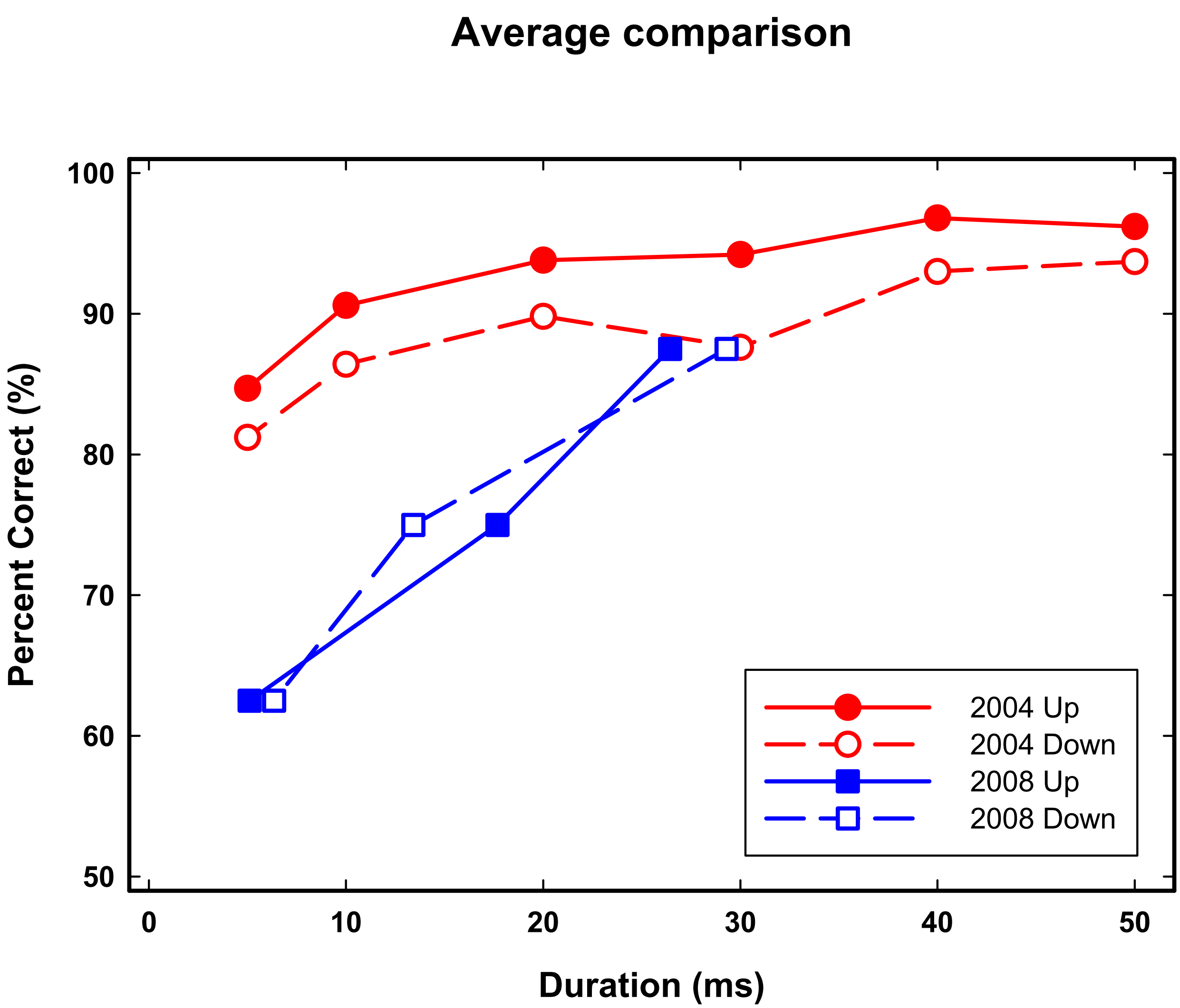

Figure 6 - Comparison of Original Dawson and Feth (2004) Experiment shown in red. UP glides represented by filled red circles, DOWN glides represented by open red circles. Results of the adaptive SIAM procedure are shown in blue. UP glides represented by filled blue circles, DOWN glide represented by open blue circles.

Subjects	Targeted Percent Correct	UP	Difference in UP	DOWN	Difference in Down
S#1	**87.50%**	94%	6.50%	81.33%	-6.17%
	75%	72.89%	-2.11%	74.22%	-0.80%
	62.50%	76.89%	14.39%	74%	11.50%
S#2	**87.50%**	88%	0.50%	96.89%	1.89%
	75%	84.89%	9.89%	84.44%	9.40%
	62.50%	65.56%	3.06%	66%	3.50%
S#3	**87.50%**	87.78%	0.28%	89.33%	1.83%
	75%	76.89%	1.89%	73.56%	-1.44%
	62.50%	72.89%	10.39%	72%	9.50%
S#4	**87.50%**	95.33%	7.89%	93.11%	5.61%
	75%	90%	15.00%	75.33%	0.33%
	62.50%	68.89%	6.39%	66.44%	3.94%

Table 7 –Individual subject projected percent correct for "Up" tone glides and "Down" tone glides for the non-adaptive procedure. The table also represents the difference between the targeted percent correct and the actual percent correct for "Up" and "Down" tone glides in the non-adaptive procedure.

Chapter 4 – Discussion

Earlier studies by Gordon and Poeppel (2002) and Dawson and Feth (2004) reported that human listeners could identify rising tone glides more accurately than falling tone glides. Additionally, they had determined that performance increases when the frequency and duration increases. Dawson and Feth's study focused on replicating the results of Gordon and Poeppel study with virtual-frequency (VF) glides and frequency-modulated (FM) glides. Dawson and Feth discussed that VF glides and FM glides should have a similar pattern in direction identification that was found by Gordon and Poeppel in FM glides.

Originally, Dawson and Feth (2004) had difficulty producing the same results found in the Gordon and Poeppel (2002) study. The task proved to be quite easy for the subjects with very little practice. Roving of the tone glide had to be introduced before the direction identification experiment could begin. By roving the frequencies, the listener had to listen to the full duration of the whole stimulus. The glide could start anywhere within a fixed range of a particular center frequency and either move upward or downward in frequency. After analyzing their data, they found the same results as Gordon and Poeppel where subjects were able to identify rising tone glides more accurately than falling tone glides.

The question that the present study had to ask was: Did the results of the present study agree with those found by Gordon and Poeppel (2002) and Dawson and Feth (2004)? The data collected in this study do not support the previous studies in direction identification. Primarily, there was no difference in sensitivity between rising or falling tone glides in the two studies. The adaptive experiment using the SIAM procedure and the non-adaptive procedure using a simple "yes-no" procedure both expressed that the four subjects did not show a big difference between the rising tone glide and falling tone glide; however, when two subjects did show a sensitivity they favored the “Down” tone glide. Due to the difference in results between this study and previous studies some other questions must be addressed.

Did the adaptive SIAM procedure control for response bias and was the response bias evident in the non-adaptive procedure like the previous studies? Analysis of the data shows that the one-interval adjustment-matrix (SIAM) procedure did in fact control for response bias. The SIAM procedure regulates the duration of the stimulus depending on the performance of the subjects. The duration of the signal decreases as the listener correctly responds to the tone glide. When a response is incorrect, the signal begins to increase again using a staircase technique. This method has proven as the fastest unbiased procedure because the number of trials decreases for each time block. Another benefit of the SIAM procedure was having the program calculate the hit, miss, correct rejection, and false alarm rates. The adjustment matrix changes the duration of the signal depending on if the subject gets a hit vs. a miss, and a different duration for a false alarm vs. a correct rejection. By changing the duration for each response the SIAM procedure controls for response bias. In addition, many one-interval procedures do not give this kind of information.

There could be many reasons for the difference in results between the previous studies and the present study. One of the reasons could be that the subjects were more experienced in hearing tone glides and were able to identify rising and falling tone glides better than the previous years. Another reason could be the different procedures where the subjects heard the stimulus through the SIAM procedure and had to listen to the whole stimulus before identifying if it was a rising tone glide or a falling tone glide. Additionally, this could be due to the different processing in the auditory system in rising and falling tone glides. Finally, the gender of our subjects could have contributed to the difference in sensitivity because we only used female undergraduates. This is one of the weaknesses of this study because the data did not include any male results. Another downfall of this study was only having four subjects to participate. This does not give enough data to know how a population would identify a rising or falling tone glide. Finally, one might suggest using more center frequencies in the present setup. When there are time constraints it is helpful to use three center frequencies: 734, 1224, and 2449 Hz.

Though this study did find different results than the previous studies it gives more information on how direction identification is heard by subjects. Additionally, it shows that there may be some people who do not favor rising tone glides or falling tone glides. This information can help researchers understand more about direction identification and how they should be aware of possible response bias in any study. Finally, future research should focus on the brain activity of the central auditory system and how the brain identifies rising and falling tone glides with no difference in sensitivity.

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Appendix

		UP								
		2449			1224			734		
S	Trials	87.5	75	62.5	87.5	75	62.5	87.5	75	62.5
S#1	#1	11.5	9.22	4.92	16.33	6.22	2.6	12	8.88	4
	SD	4.04	1.72	3.45	3.21	2.33	3.29	4	2.1	3.54
	#2	16.5	12.33	4.64	14.67	8.78	3.4	14.4	9.85	6.63
	SD	4.43	1.26	3.29	4.62	1.48	3.85	3.85	1.86	3.62
	#3	13.6	10.77	1.1	11.67	7.2	1.45	15.2	12.33	3.89
	SD	3.05	1.48	1.66	3.21	2.77	2.16	3.27	3.97	3.53
	Avg Mean	13.8666667	10.7733333	3.55333333	14.2233333	7.4	2.48333333	13.8666667	10.35333333	4.84
	Avg SD	3.84	1.48666667	2.8	3.68	2.19333333	3.1	3.70666667	2.643333333	3.563333333
S#2	#1	97.81	33	5	22	52	4.44	18	17	3.55
	SD	5.31	2.94	3.92	4	3.38	4.64	0	1.19	3.7
	#2	68.2	13.88	17.5	39.83	25.57	11.72	19	20	2.64
	SD	3.56	2.03	3.92	3.66	4.89	3.83	4.36	2.08	3.1
	#3	58.57	33.67	4.25	30.33	44.55	4.13	17.4	16.44	3.27
	SD	5.53	3.94	3.45	5.36	2.02	3.36	3.36	1.81	3.61
	Avg Mean	74.86	26.85	8.91666667	30.72	40.7066667	6.76333333	18.1333333	17.81333333	3.153333333
	Avg SD	4.8	2.97	3.76333333	4.34	3.43	3.94333333	2.57333333	1.693333333	3.47
S#3	#1	13.33	8	3.54	13.33	12.22	4.64	23.71	10.33	1
	SD	5.03	2	3.48	3.06	1.64	5.22	3.64	1.58	1.66
	#2	16.33	7	4	9.67	12.33	4.13	28.67	10.57	0.56
	SD	3.21	1.41	3.16	3.21	4.73	3.64	5.03	2.15	0.76
	#3	13	2.43	3	5.67	13.63	4.47	20.57	7.78	0.6
	SD	2.45	0.98	3.32	3.21	2.62	4.69	3.51	1.79	0.89
	Avg Mean	14.22	5.81	3.51333333	9.55666667	12.7266667	4.41333333	24.3166667	9.56	0.72
	Avg SD	3.56333333	1.46333333	3.32	3.16	2.99666667	4.51666667	4.06	1.84	1.103333333
S#4	#1	10	17.77	12.77	39	30.5	12.2	59.92	26.56	9.82
	SD	0	1.59	3.09	3.22	3.23	5.6	4.44	3.09	4.16
	#2	10	10.91	7	21	39.14	5.3	45.67	36.25	10.88
	SD	0	1.7	3.11	4.36	3.44	5.08	5.39	1.49	4.77
	#3	58	12.56	8.59	22.71	35.69	5.35	44.09	25.73	9.87
	SD	4.24	2.65	3.76	4.75	2.78	3.42	4.64	2.45	3.98
	Avg Mean	26	13.7466667	9.45333333	27.57	35.11	7.61666667	49.8933333	29.51333333	10.19
	Avg SD	1.41333333	1.98	3.32	4.11	3.15	4.7	4.82333333	2.343333333	4.303333333

Table A

Table B

DOWN										
2449					1224			734		
87.5	**75**	**62.5**	**S**	**Trials**	**87.5**	**75**	**62.5**	**87.5**	**75**	**62.5**
11.61	10.75	1.73	*S#1*	#1	18.6	1	5.38	17.33	0.6	2.43
3.21	2.38	2.05		SD	4.04	0.93	4.17	4.16	0.89	2.5
12.25	12	0.57		#2	11	2.6	4.92	13	1.6	8.47
2.87	1.95	0.79		SD	2.45	2.19	3.28	3	1.17	3.62
8.33	2.33	1.8		#3	3.37	7.75	9.73	14.6	4.5	4.4
4.04		3.49		SD		1.71	3.61	3.21	1.69	3.53
10.73	8.36	1.366666667		**Avg Mean**	10.99	3.783333333	6.676666667	14.97666667	2.233333333	5.1
3.373333333	2.165	2.11		**Avg SD**	3.245	1.61	3.686666667	3.456666667	1.25	3.216666667
32	15.2	13.08	*S#2*	#1	71.6	43.64	6.31	80.77	20.86	4.27
0	3.27	3.92		SD	3.91	2.34	4.13	4.49	1.68	2.97
63.44	13	7.42		#2	33.57	33.36	12.47	79.9	21.22	5.1
2.96	2.45	5.14		SD	2.99	1.75	4.07	2.08	1.79	2.81
14.5	15.97	16.08		#3	27.33	37.91	9.14	31.5	37.29	2.71
3.39	4.23	4.61		SD	3.06	2.39	4.64	1.29	2.29	3.68
36.64666667	14.72333333	12.19333333		**Avg Mean**	44.16666667	38.30333333	9.306666667	64.05666667	26.45666667	4.026666667
2.116666667	3.316666667	4.556666667		**Avg SD**	3.32	2.16	4.28	2.62	1.92	3.153333333
24.33	3.9	0	*S#3*	#1	19.8	3.67	5.33	18	12.6	11.84
3.21	1.37	0		SD	3.77	1.66	6.11	4	1.5	3.08
28.4	18.14	0		#2	25	6	5.33	13	12.7	12.2
3.85	1.77	0		SD	4.36	2.77	6.11	4.36	1.57	6.29
20	10.2	0		#3	16.67	2.57	2.67	20.2	10.9	14.33
3.16	1.32	0		SD	4.16	2.15	4.62	3.77	1.45	7.54
24.24333333	10.74666667	0		**Avg Mean**	20.49	4.08	4.443333333	17.06666667	12.06666667	12.79
3.406666667	1.486666667	0		**Avg SD**	4.096666667	2.193333333	5.613333333	4.043333333	1.506666667	5.636666667
37.33	22.63	19.08	*S#4*	#1	10.67	7	6.38	44.4	14.13	8.45
3.06	3.25	4.27		SD	4.16	3.87	5.17	3.36	1.73	4.23
18.8	19	5.5		#2	20.5	0.8	4.82	52.29	15.44	3
4.09	2.45	4.43		SD	6.36	1.3	4.09	2.36	1.42	5.2
30.6	18.57	5		#3	29.33	5	4.45	63.11	9.92	4
4.04	1.81	5.81		SD	4.19	1.26	4.89	4.48	1.16	3.36
28.91	20.06666667	9.86		**Avg Mean**	20.16666667	4.266666667	5.216666667	53.26666667	13.16333333	5.15
3.73	2.503333333	4.836666667		**Avg SD**	4.903333333	2.143333333	4.716666667	3.4	1.436666667	4.263333333

Table A and B - Above Tables are Individual subject statistical results from the adaptive procedure. Mean and standard deviation was calculated for the “Up” and “Down” tone glides for each center frequency.

Table C

			UP								
			2449			1224			734		
S			**87.5**	**75**	**62.5**	**87.5**	**75**	**62.5**	**87.5**	**75**	**62.5**
S#1	#1	Hits	22	18	20	25	18	18	23	22	19
		Rejection	25	14	13	23	15	15	22	18	18
	#2	Hits	23	19	22	27	21	20	23	19	25
		Rejection	26	15	16	22	17	19	23	22	21
	#3	Hits	23	17	20	23	23	21	20	20	23
		Rejection	25	11	17	24	16	15	24	23	24
		avg hits	22.66666667	18	20.6666667	25	20.66666667	19.66666667	22	20.33333333	22.33333333
		avg rej	25.33333333	13.3333333	15.3333333	23	16	16.33333333	23	21	21
S#2	#1	Hits	25	22	16	23	25	10	19	17	16
		Rejection	23	23	17	25	25	22	17	17	23
	#2	Hits	26	25	14	23	23	16	18	18	14
		Rejection	23	23	17	19	23	23	18	16	19
	#3	Hits	24	25	14	21	23	17	23	17	12
		Rejection	24	23	10	23	23	21	22	14	14
		avg hits	25	24	14.6666667	22.33333333	23.66666667	14.33333333	20	17.33333333	14
		avg rej	23.33333333	23	14.6666667	22.33333333	23.66666667	22	19	15.66666667	18.66666667
S#3	#1	Hits	22	21	24	19	19	16	21	18	14
		Rejection	25	18	16	17	19	18	26	16	17
	#2	Hits	24	19	20	22	22	21	25	20	17
		Rejection	24	19	19	15	20	16	25	15	15
	#3	Hits	23	24	19	21	18	22	26	22	18
		Rejection	19	21	18	19	21	19	22	14	19
		avg hits	23	21.3333333	21	20.66666667	19.66666667	19.66666667	24	20	16.33333333
		avg rej	22.66666667	19.3333333	17.6666667	17	20	17.66666667	24.33333333	15	17
S#4	#1	Hits	26	23	17	25	24	19	25	24	18
		Rejection	22	18	17	25	22	18	22	23	16
	#2	Hits	25	24	21	25	25	21	21	22	16
		Rejection	23	20	12	23	24	19	25	25	17
	#3	Hits	23	22	18	23	21	20	25	23	16
		Rejection	23	23	12	25	19	18	23	23	15
		avg hits	24.66666667	23	18.6666667	24.33333333	23.33333333	20	23.66666667	23	16.66666667
		avg rej	22.66666667	20.3333333	13.6666667	24.33333333	21.66666667	18.33333333	23.33333333	23.66666667	16

Table D

DOWN								
2449			1224			734		
87.5	75	62.5	87.5	75	62.5	87.5	75	62.5
15	16	13	22	17	17	24	16	23
16	18	18	23	25	24	23	21	23
16	14	13	13	15	20	24	15	21
21	18	19	21	22	23	25	22	15
15	14	13	17	22	18	23	16	21
24	18	15	22	24	24	22	21	13
15.33333333	14.66666667	13	17.33333333	18	18.33333333	23.66666667	15.66666667	21.66666667
20.33333333	18	17.33333333	22	23.66666667	23.66666667	23.33333333	21.33333333	17
24	22	17	24	23	18	24	24	18
25	19	14	23	20	13	26	19	15
23	23	15	25	24	21	22	22	18
25	18	17	23	26	16	25	18	18
25	22	17	24	22	13	24	20	17
25	16	14	23	24	19	26	18	17
24	22.33333333	16.33333333	24.33333333	23	17.33333333	23.33333333	22	17.66666667
25	17.66666667	15	23	23.33333333	16	25.66666667	18.33333333	16.66666667
24	16	15	23	20	17	19	17	17
24	19	21	24	22	17	23	17	16
23	14	18	25	22	15	21	15	15
22	18	18	24	24	18	21	19	19
19	18	20	25	18	18	23	18	18
20	15	24	23	21	21	19	18	17
22	16	17.66666667	24.33333333	20	16.66666667	21	16.66666667	16.66666667
22	17.33333333	21	23.66666667	22.33333333	18.66666667	21	18	17.33333333
23	25	13	24	12	16	25	14	16
22	24	20	22	20	19	19	15	18
24	23	8	19	13	19	25	15	16
25	26	24	25	22	14	23	19	18
22	23	15	22	10	18	25	14	16
25	26	19	25	20	17	24	18	13
23	23.66666667	12	21.66666667	11.66666667	17.66666667	25	14.33333333	16
24	25.33333333	21	24	20.66666667	16.66666667	22	17.33333333	16.33333333

Table C and D – Individual subject statistical results of the non-adaptive procedure. Individual calculations for hits and correct rejection for “Up” and “Down” tone glide for each center frequency.